ONR

Yearly Report

Silicon Association Cortex
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Technical Accomplishments

Under this grant research is conducted at both Adaptive Systems Inc. (ASI) and the Oregon Graduate Institute (OGI). ASI is developing hardware implementations of models derived from studies of olfactory cortex. For these implementations the models are being mapped onto the general-purpose neurocomputer developed at ASI. Research at ASI is also directed towards direct silicon implementation of biologically faithful cortex models.

Research at OGI is concerned with the computational capability and theoretical aspects of these models, as well as with modifications that enhance functionality. We are applying cortex-inspired models to speech recognition problems as well as pursuing issues of model convergence and computational efficiency.

Implementation on High-level Simulator (OGI) The abstract cortex model [1] was implemented in ASI's high-level simulator. This was the first step in mapping the algorithm to ASI's neuro-computer. This implementation provides a template for the direct micro-code implementation on the chip. In addition, this simulator provided us with a vehicle for preliminary studies of the clustering and classification ability of the model.

Implementation in Micro-Code (ASI) We have completed a direct micro-code implementation of the model for the ASI neuro-computer. The code includes embellishments to the algorithm developed by the research group at OGI. Details of the implementation appear in [2].

Computational Capability (OGI) In [3] we have shown that the abstract model described in [1] and implemented on the ASI neurocomputer is a neural implementation of multistage vector quantization [4, 5]. This architecture has a significant storage advantage relative to conventional neural clustering and vector quantization (VQ) algorithms.

Standard neural VQ algorithms require one neuron for each cluster point. That is, each neuron responds to a specific region of the input space. This defines the receptive field of the neuron.

The multi-stage architecture defines cluster points by *combinations* of neural receptive fields. For example, a cortex model with three hierarchical levels of four neurons each generates 64 distinct cluster points using only 12 neurons. A conventional competitive learning algorithm requires 64 neurons to define the same number of cluster points. Our experiments confirm that the cortex model when used for encoding and classifying phonemes provides lower error per neuron than either conventional or tree-structured algorithms [3].

Naturally one does not get something for nothing, and there is a tradeoff inherent in the multi-stage structure. Since each neuron in the model participates in defining several clusters, the latter cannot be independently oriented. However, the disadvantage of this constraint appears to be overwhelmed by the advantage gained by the combinatorial efficiency.

Noise Immunity (OGI/ASI) Noise immunity is an issue for both biological and limited-precision hardware implementations of neural algorithms. While many simulations are carried out using double-precision floating point operations, biological systems cannot approach this level of precision. Inexpensive neural computers must forgo the luxury of floating point processors.

We have conducted preliminary studies using an algorithm that rescales pattern vectors to mock-up the approximate constancy of olfactory bulb excitation. We find some improvement in noise immunity, with further studies suggested. The current hardware implementation includes an option to excercise this embellishement.

Model Dynamics (OGI) We began studies of the dynamics of self-organizing networks under a previous ONR grant and completed that work under

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the present grant. (Cliff Lau served as science officer for the previous grant, No. N00014-88-K-0329.) We introduced tools from bifurcation theory to treat the dynamics of *learning* in networks with both Hebbian and anti-Hebbian synapses and recurrent lateral connections. Our studies identify the bifurcation types and thus provide *analytic* descriptions of the location of equilibria and limit cycles in the learning behavior.

Our paper describing this work was among fewer than 6 % of the submitted papers chosen for oral presentation at the 1990 Neural Information Processing Systems conference at Denver, Colorado [6]. The work was recently published in *Network : Computation in Neural Systems* [7] and is the subject of invited talks at the 1990 International Society for the Systems Sciences and the 1991 SPIE Conference on Adaptive Signal Processing.

Publications

Refereed Papers – 4

1. Leen, T.K.: Dynamics of learning in linear feature-discovery networks, *Network: Computation in Neural Systems* **2**, 85, 1991.

2. Leen, T.K.: Weight-Space Dynamics of Recurrent Hebbian Networks, to appear in *Advances in Neural Information Processing Systems 3*, Morgan Kauffman, 1991.

3. Leen, T.K., Webb, Max, Rehfuss, S.: Encoding and Classification in a Model of Olfactory Cortex, to appear in *International Joint Conference on Neural Networks*, 1991.

4. Means, E. and Hammerstrom, D.: Piriform model execution on a neurocomputer, to appear in *International Joint Conference on Neural Networks*, 1991.

Book Chapters – 2

1. Hammerstrom, D., Leen, T.K., and Means, E.: Dynamics and Implementation of Self-Organizing Networks, in *Advanced Neural Computers*, R. Eckmiller (Ed.), Elsevier Science Publishers B.V. (North-Holland), March, 1990.

2. Hammerstrom, D. and Means, E.: A proposed architecture for a second-generation neurocomputer, in *Olfaction as a Model Systems for Computational Neuroscience*, Joel Davis and Howard Eichenbaum (Eds.), MIT Press, 1991.

Technical Reports and Non-Refereed Papers – 6

1. Leen, T.K.: Weight Dynamics of Recurrent Hebbian Networks, *Proceedings of the 34th Annual conference of the International Society for the Systems Sciences, July, 1990.*
2. Leen, T.K.: Hebbian Learning: Algorithms and Applications, *Proceedings of the 34th Annual conference of the International Society for the Systems Sciences, July, 1990.*
3. Leen, T.K.: Dynamics of Learning in Recurrent Hebbian Networks, *Oregon Graduate Institute Technical Report No. CSE 90-013*, August, 1990.
4. Leen, T.K., Cole, R., Hammerstrom, D., Inouye, J. : Speech Recognition with a Cortex Model : Preliminary Results and Outlook, *Oregon Graduate Institute Technical Report No. CSE 90-022*, June, 1990.
5. Leen, T.K., Webb, Max, Rehfus, S.: Encoding and classification in a model of olfactory cortex, *Oregon Graduate Institute Tech. Rep. CS/E 91-002*, Jan. 1991.
6. Leen, T.K.: Neural Network Data Encoding and PCA, *Neural Network Review*, 1991 (in press).

Refereed Papers Submitted, Not Yet Published – 1

1. Leen, T.K., Webb, M., Rehfuss, S.: "Hierarchical Competitive Learning and Olfactory Cortex", submitted to Neural Information Processing Systems, 1991.

Invited Talks – 2

1. Todd K. Leen, "Local Learning in Hebbian Networks, R.S. Dow Neurological Sciences", Institute, Feb. 1991.

2. Todd K. Leen, "Bifurcations in Learning", SPIE Conference on Adaptive Signal Processing, to appear July, 1991.

Patents – 0

Support

- Graduate Students Supported Greater than 25% – 2.
- Post-doc support – 0.
- Female, minority and Asian graduate students and post-docs – 0.

References

[1] Jose Ambros-Ingerson, Richard Granger, and Gary Lynch. Simulation of paleocortex performs hierarchical clustering. *Science*, 247:1344–1348, 1990.

[2] Eric Means and Dan Hammerstrom. Piriform model execution on a neurocomputer. In *Proceedings of the 1991 International Joint Conference on Neural Networks*, June 1991, submitted.

[3] Todd K. Leen, Max Webb, and Steven Rehfuss. Encoding and classification in a model of olfactory cortex. In *Proceedings of the IJCNN*, June to appear 1991.

[4] Biing-Hwang Juang and A.H. Gray Jr. Multiple stage vector quantization for speech coding. In *Proceeding of the IEEE International Conference on Acoustics and Signal Processing*, pages 597–600, 1982.

[5] Robert M. Gray. Vector quantization. *IEEE ASSP Magazine*, pages 4–29, April 1984.

[6] Todd Leen. Dynamics of learning in recurrent feature-discovery networks. In Richard P. Lippmann, John Moody, and David Touretzky, editors, *Advances in Neural Information Processing Systems 3*. Morgan Kauffmann, to appear 1991.

[7] Todd K. Leen. Dynamics of learning in linear feature-discovery networks. *Network : Computation in Neural Systems*, 2:85–105, 1991.